Environment International 119 (2018) 309–318

Contents lists available at ScienceDirect

Environment International

journal homepage: www.elsevier.com/locate/envint

# Co-benefits of climate mitigation on air quality and human health in Asian countries

Yang Xie[a,b], Hancheng Dai[c,*], Xinghan Xu[d], Shinichiro Fujimori[b,d], Tomoko Hasegawa[b], Kan Yi[e], Toshihiko Masui[b], Gakuji Kurata[d]

[a] School of Economics and Management, Beihang University, Beijing 100191, China
[b] Center for Social and Environmental Systems Research, National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba-City, Ibaraki 305-8506, Japan
[c] College of Environmental Sciences and Engineering, Peking University, Beijing 100871, China
[d] Department of Environmental Engineering, Kyoto University, Nishikyo-ku, Kyoto 615-8540, Japan
[e] College of Urban and Environmental Sciences, Peking University, Beijing 100871, China

ARTICLE INFO

Handling Editor: Yong Guan Zhu

*Keywords:*
Air quality
Health co-benefit
Climate mitigation
Economic impact
CGE

ABSTRACT

Climate change mitigation involves reducing fossil fuel consumption and greenhouse gas emissions, which is expensive, particularly under stringent mitigation targets. The co-benefits of reducing air pollutants and improving human health are often ignored, but can play significant roles in decision-making. In this study, we quantified the co-benefits of climate change mitigation on ambient air quality and human health in both physical and monetary terms with a particular focus on Asia, where air quality will likely be degraded in the next few decades if mitigation measures are not undertaken. We used an integrated assessment framework that incorporated economic, air chemistry transport, and health assessment models. Air pollution reduction through climate change mitigation under the 2 °C goal could reduce premature deaths in Asia by 0.79 million (95% confidence interval: 0.75–1.8 million) by 2050. This co-benefit is equivalent to a life value savings of approximately 2.8 trillion United States dollars (USD) (6% of the gross domestic product [GDP]), which is decidedly more than the climate mitigation cost (840 billion USD, 2% of GDP). At the national level, India has the highest potential net benefit of 1.4 trillion USD, followed by China (330 billion USD) and Japan (68 billion USD). Furthermore, in most Asian countries, per capita GDP gain and life value savings would increase with per capita GDP increasing. We robustly confirmed this qualitative conclusion under several socioeconomic and exposure-response function assumptions.

## 1. Introduction

The majority of countries around the world have made greenhouse gas (GHG) reduction targets and submitted them to the Paris Agreement. However, policymakers generally hesitate to set more ambitious mitigation targets because climate mitigation carries economic costs, and the more ambitious the mitigation target, the higher the cost. Many studies have suggested that air pollution improvement and climate mitigation carry significant co-benefits. (Balbus et al., 2014) estimated that by 2020, reductions in adverse health outcomes due to decreased fine particulate matter ($PM_{2.5}$) exposure would save the United States 6–30 billion USD (in 2008 USD). West et al. (2013a, b) found that a representative concentration pathway 4.5 (RCP 4.5)-equivalent GHG mitigation would result in 0.5 ± 0.2, 1.3 ± 0.5, and 2.2 ± 0.8 million fewer premature deaths globally in 2030, 2050, and 2100, respectively. The co-benefit of per ton of carbon dioxide ($CO_2$) reduction is about 50–380 USD for the worldwide average, 30–600 USD for the United States and Western Europe, 70–840 USD for China, and 20–400 USD for India. The economic co-benefits are much higher in East Asia than in other regions such as U.S. and EU, approximately 10–70 times the marginal cost in 2030. McCollum et al. (2013) found that carbon reduction efforts could reduce energy-related health impacts by upwards of 2–32 million fewer disability-adjusted life years globally in 2030. A study in the United States showed that climate mitigation could prevent more than 10,000 premature deaths in 2050 and 5000 deaths in 2100 due to air quality improvement, equivalent to a value of statistical life (VSL) of approximately 150 billion USD and 1.3 trillion USD (in 2005 USD) by 2050 and 2100, respectively (Garcia-Menendez et al., 2015). Yang and Teng found that if China reduces its 2005 carbon emissions intensity by 60–65%, compared to 2010 levels, sulfur dioxide, nitrogen oxide, and $PM_{2.5}$ emissions will be reduced by 78.85%, 77.56%, and 83.32%, respectively, by 2030 (Yang and Teng,

* Corresponding author at: Room 246, Environmental Building, College of Environmental Sciences and Engineering, Peking University, Beijing 100871, China.
*E-mail address:* dai.hancheng@pku.edu.cn (H. Dai).

https://doi.org/10.1016/j.envint.2018.07.008
Received 27 March 2018; Received in revised form 4 July 2018; Accepted 4 July 2018
0160-4120/ 

2017). One study from OECD shows the global economic costs of outdoor air pollution increase to 1% of global GDP by 2060, with highest GDP losses in China (Lanzi et al., 2018).

When evaluating the economic costs of climate mitigation, it is necessary to include the potential societal benefits to more comprehensively assess the costs and benefits of various mitigation goals. Health improvement constitutes a substantial fraction of the potential benefits, along with averted adaptation costs and residual damage. Quantifying the co-benefits of climate mitigation may convince policymakers and the public to formulate integrated mitigation strategies and to adjust their lifestyles toward a green and low-carbon society (R. Xie et al., 2016). However, future GHG and air pollutant emissions are highly dependent on socioeconomic conditions and climate mitigation targets, the former of which are highly uncertain, and the latter of which are quite relevant to policy intervention. To address such uncertainties, the climate research community has made tremendous strides in developing the next generation of scenarios for climate change research (Moss et al., 2010) including shared socioeconomic pathways (SSPs) and RCPs. SSPs are stylized projections of future energy consumption and emissions that consider the challenges of vulnerabilities, adaptation, and mitigation (Kriegler et al., 2014; Fujimori et al., 2016; van Vuuren et al., 2017), whereas RCPs are a set of four new pathways developed for the climate modeling community as a basis for long-term and near-term modeling experiments (van Vuuren et al., 2012). One study in EU also found positive effect related to health can offset the resource costs associated to the clean air policy, which resulted in positive macroeconomic impacts for the economy (Vrontisi et al., 2016).

Previous studies have focused on the air quality and health benefits of climate mitigation at the aggregate global level or in developed countries such as the United States under certain socioeconomic pathways and mitigation targets. However, without consistent assumptions on socioeconomic pathways or mitigation targets, it is difficult to consistently compare the costs and benefits among various studies, which may confuse policymakers. To avoid such confusion and inconsistencies, new simulations and assessments are needed that consider the latest progress in climate scenario development such as SSPs and RCPs. Furthermore, air pollution and its impacts are less severe in developed countries than in developing countries; thus more attention should be given to emerging developing countries, particularly Asia, where several of the most populous and dynamic developing countries are located. Asian countries suffer serious negative health impacts of air pollution due to rapid economic growth and fossil energy consumption in recent decades, particularly $PM_{2.5}$ and tropospheric ozone pollution in China and India (Lelieveld et al., 2015; Rohde and Muller, 2015; Ghude et al., 2016). One study by the World Health Organization (WHO) showed that the global mortality due to air pollution exceeded 6.5 million in 2015, more than half of what occurred in Asia (Landrigan et al., 2017). Thus, Asian countries are key players and contributors in guaranteeing the success of global climate mitigation (Calvin et al., 2012; Paltsev et al., 2012).

However, few studies have investigated air quality and health benefits in Asian countries. Moreover, a limitation of most existing studies is that they typically adopted a one-way assessment; air pollutant emissions from the economic system deteriorate air quality, causing adverse health impacts, and policy interventions will ease these negative impacts through the chain, and are defined as benefits. However, the feedback effects of adverse and improved health impacts on the economic system are not reflected in such approaches. Based on this premise, we selected Asian countries as target regions, and SSP2 combined with the 3.4 W/m$^2$ forcing target in 2100 as representative climate scenarios. We aimed to distinguish the costs and benefits of climate mitigation moving toward 2050 in Asia. Moreover, we adopted a novel methodology that closes the economy-environment-health-economy loop by combining an air chemistry transport model, an economic model, and a health assessment model to account for the complex interactions among the environment, human health, and economic systems. Our study also provides sensitivity analyses under alternative socioeconomic conditions.

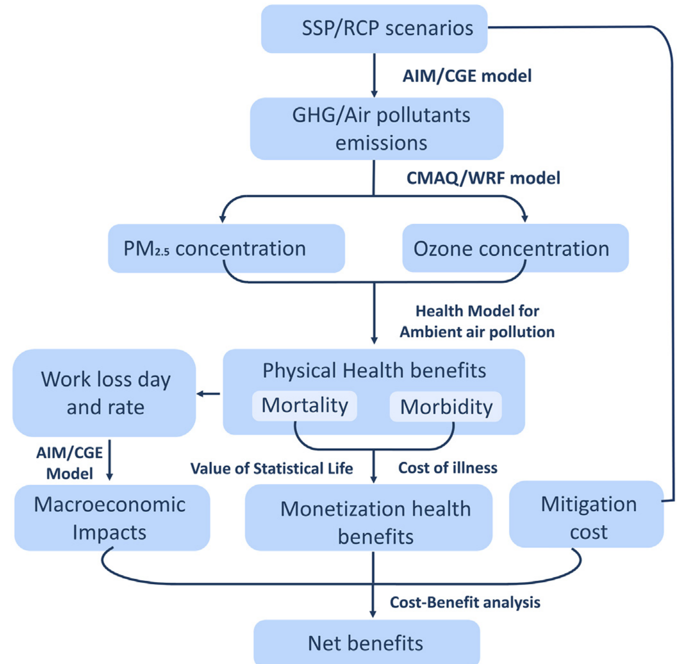


**Fig. 1.** Research framework.

## 2. Methodology

We combined the Community Multiscale Air Quality (CMAQ) model, a health assessment model, and the Asia-Pacific Integrated Assessment/Computable General Equilibrium (AIM/CGE) model to evaluate the long-term health and economic impacts caused by ambient $PM_{2.5}$ and ozone pollution under different climate mitigation and SSP2 scenarios in Asian countries (Fig. 1). Emissions data is taken from the SSP database generated by the AIM/CGE model (Fujimori, Hasegawa et al., 2017; Fujimori et al., 2016) and downscaled to a 0.5° grid (Fujimori, Abe et al. 2017). Based on the gridded emissions data, the CMAQ model simulated the annual average $PM_{2.5}$ and daily 8 h maximum ozone concentrations in 2005 and 2050. The health assessment model quantified health impacts due to outdoor air pollution, which are categorized as morbidity and mortality and monetized as additional medical expenditures and VSL. Furthermore, health impacts due to mortality and morbidity were converted into per capita work time loss, which was used as a change in the labor participation rate in the AIM/CGE model to identify macroeconomic impacts. Finally, cost-benefit analyses were conducted to determine the net benefit of climate mitigation in different regions of Asia. The per capita benefit is from net co-benefit dividing the total population in each country. This methodological framework was developed in our previous studies on China (Y. Xie et al., 2016, Wu et al., 2017, Tian et al., 2018) and extended to all of Asia in this study.

### 2.1. AIM/CGE global model

The AIM/CGE global model is a multi-regional, multi-sectoral, and multi-gas recursive dynamic CGE model (described in detail in Fujimori et al., 2012; Fujimori et al., 2016; and Masui et al., 2010) (Masui et al., 2010; Fujimori et al., 2016; Fujimori, Abe et al. 2017; Fujimori, Hasegawa et al., 2017). This model was developed to analyze energy, land use, agriculture, emissions, and climate policy at the global level, with a primary focus on Asian regions. The roles of the AIM/CGE model